JUNO ORBIT DETERMINATION EXPERIENCE DURING FIRST YEAR AT JUPITER

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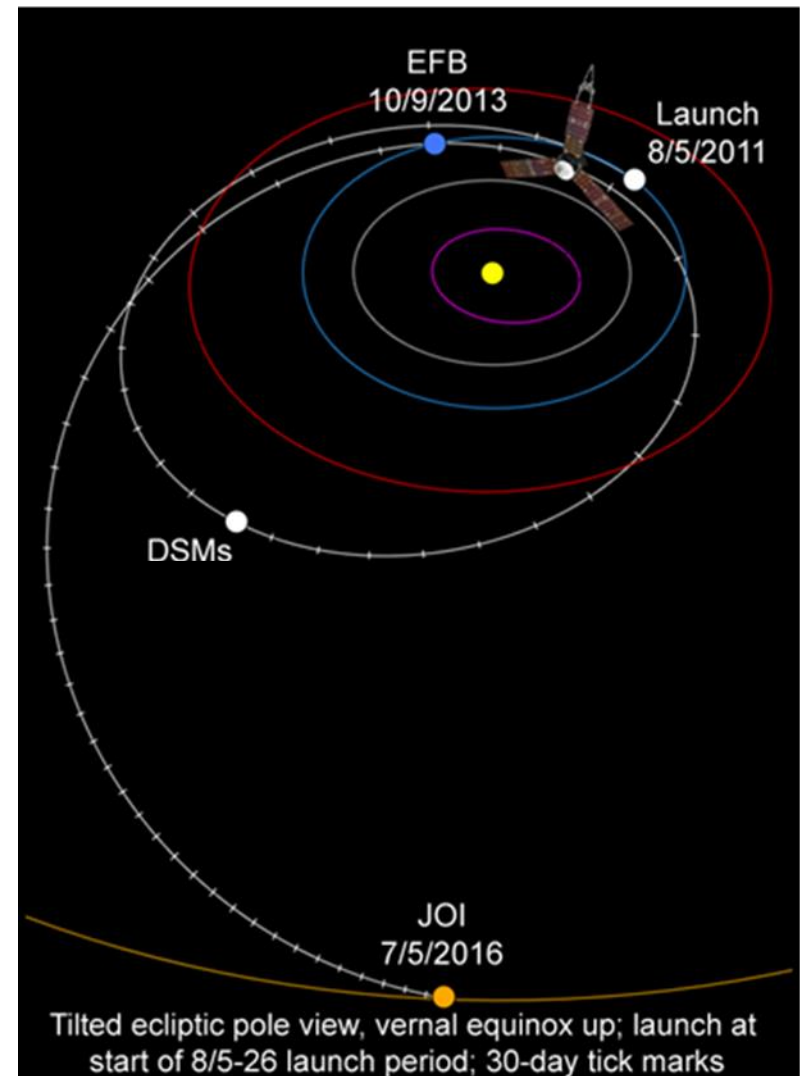**California Institute of Technology**

Introduction

- **NASA New Frontiers Mission**

- **Launched: 05-Aug-2011   JOI: 05-Jul-2016**
  - **Included 500-km altitude, Earth gravity assist (EGA) to gain energy needed to reach Jupiter**
  - **Science phase at Jupiter of highly elliptical, near-polar 53-day orbits**

- **Payload of nine instruments:**
  - *Determine how much water is in Jupiter's atmosphere, which helps determine which planet formation theory is correct (or if new theories are needed)*
  - *Look deep into Jupiter's atmosphere to measure composition, temperature, cloud motions and other properties*
  - *Map Jupiter's magnetic and gravity fields, revealing the planet's deep structure*
  - *Explore and study Jupiter's magnetosphere near the planet's poles, especially the auroras – Jupiter's northern and southern lights – providing new insights about how the planet's enormous magnetic force field affects its atmosphere.*
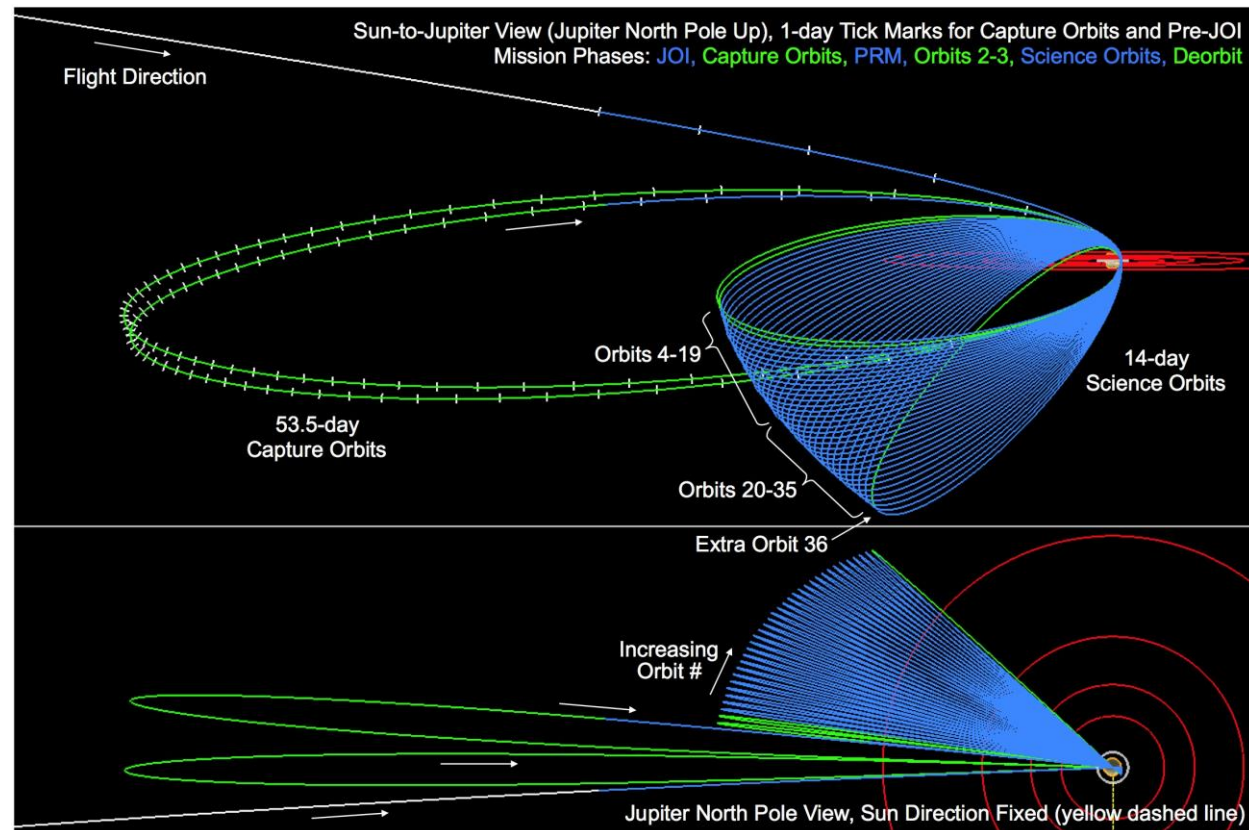
Maneuvers: Launch to Earth Gravity Assist (EGA)

- **Launch: 05-Aug-2011**
- **DSM-1 & 2: 30-Aug & 14-Sep-2012**
  - **Deep space maneuver done in two segments.**
  - **Limited Earth impact probability via a biased aimpoint, off EGA target**
- **Trajectory Correction Maneuvers:**
  - **TCM-6,7,8 to aimpoint for EGA**
    - TCM-6 at EGA – 63 days
    - TCM-7 at EGA – 30 days
    - TCM-8 at EGA – 10 days
  - **CAM (collision avoidance maneuver), to avoid a tracked Earth-orbiting object**
    - CAM at EGA – 12 hours
  - **TCM-8 and CAM cancelled**
  - *Only TCM-6 and 7 were executed.*
- **EGA: 09-Oct-2013**
  - **Provided delta-V to get Juno to Jupiter**

EFB
10/9/2013

Launch
8/5/2011

DSMs

JOI
7/5/2016

Tilted ecliptic pole view, vernal equinox up; launch at start of 8/5-26 launch period; 30-day tick marks

Maneuvers: EGA to JOI-CLN

- **EGA: 09-Oct-2013**
- **TCM-9: 13-Nov-2013**
  - **EGA clean-up maneuver**
- **TCM-10: Cancelled**
- **TCM-11: 03-Feb-2016**
  - **Targeting to JOI**
- **TCM-12: Cancelled**
- **TCM-12a: Cancelled**
- **TCM-13: Cancelled**
- **JOI: 05-Jul-2016**
  - **Capture orbit of 53.5-day period**
- **JOI-CLN: 13-Jul-2016**
  - **Clean-up errors in flyby & JOI and target PJ01**

Mission design at the time of JOI

Sun-to-Jupiter View (Jupiter North Pole Up), 1-day Tick Marks for Capture Orbits and Pre-JOI
Mission Phases: JOI, Capture Orbits, PRM, Orbits 2-3, Science Orbits, Deorbit

Flight Direction

Orbits 4-19

14-day Science Orbits

53.5-day Capture Orbits

Orbits 20-35

Extra Orbit 36

Increasing Orbit #

Jupiter North Pole View, Sun Direction Fixed (yellow dashed line)

- **PJ01: 27-Aug-2016**
  - OTM01(PJ+18days)
- ~~**Period Reduction Maneuver (PRM)**~~
  - **Sticky check-valve**
- **PJ02: 19-Oct-2016**
  - **s/c safe mode**
  - OTM02(PJ+6days)
- **PJ03: 11-Dec-2016**
  - OTM03(PJ+7.5hrs)
- **PJ04: 02-Feb-2017**
  - OTM04(PJ+7.5hrs)
  - APO04(PJ+20days)
- **PJ05: 27-Mar-2017**
  - OTM05(PJ+7.5hrs)
- **PJ06: 19-May-2017**
- **All STMs were cancelled!**
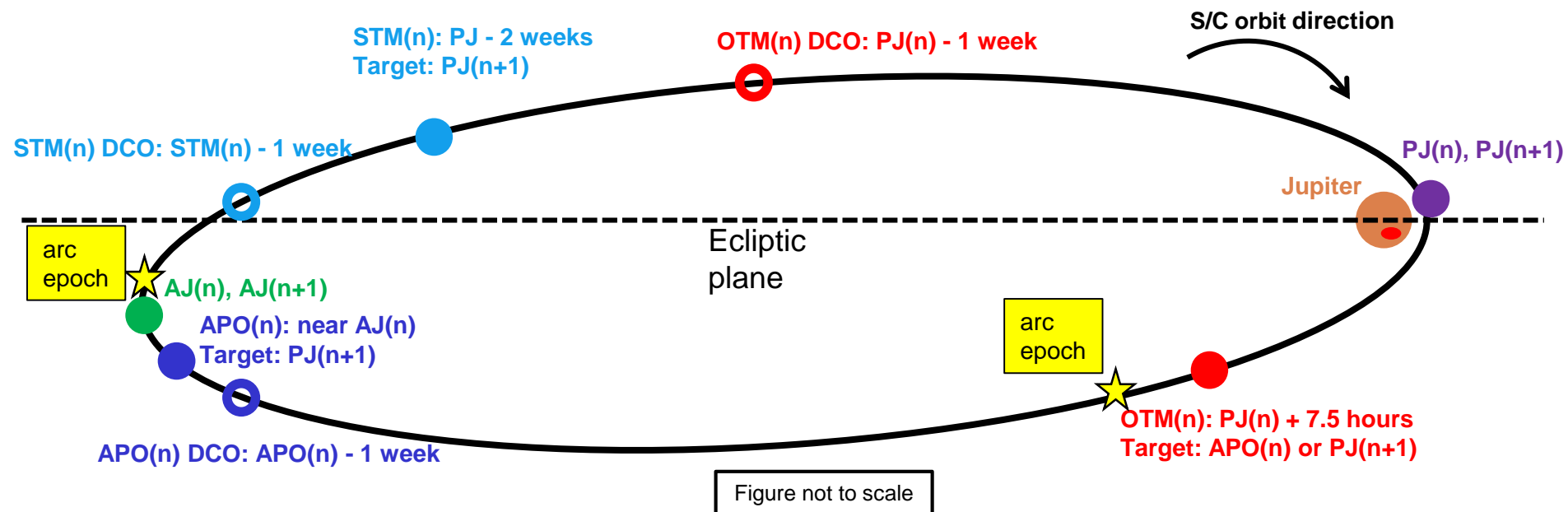
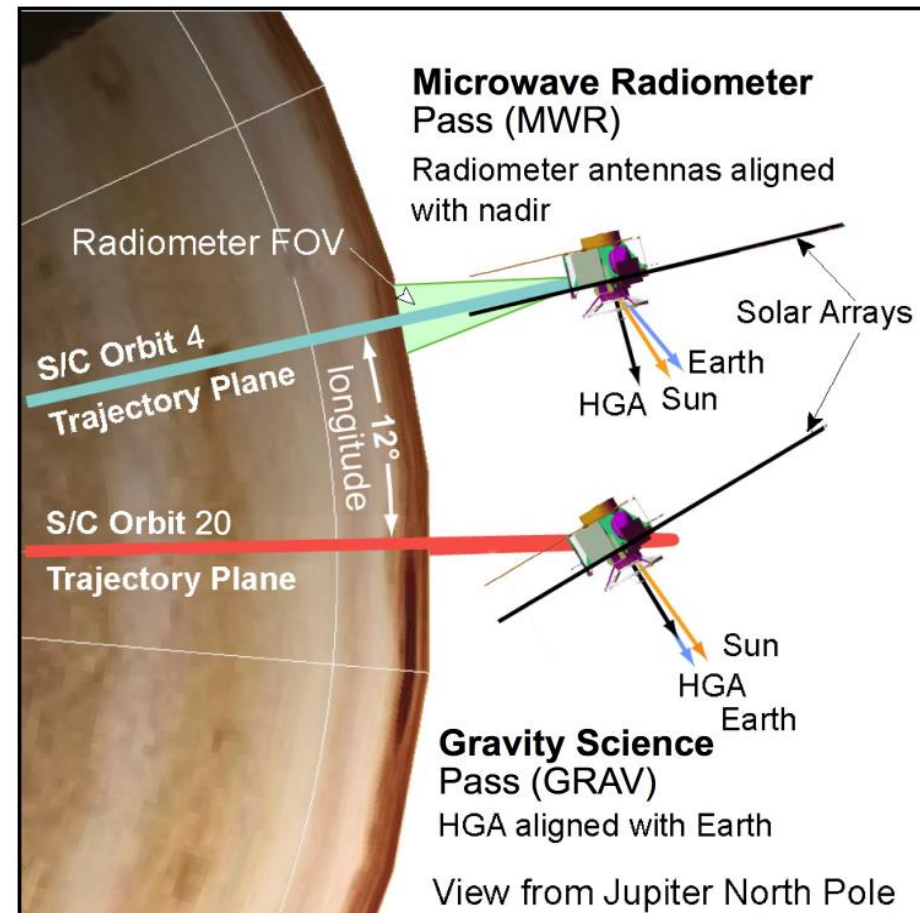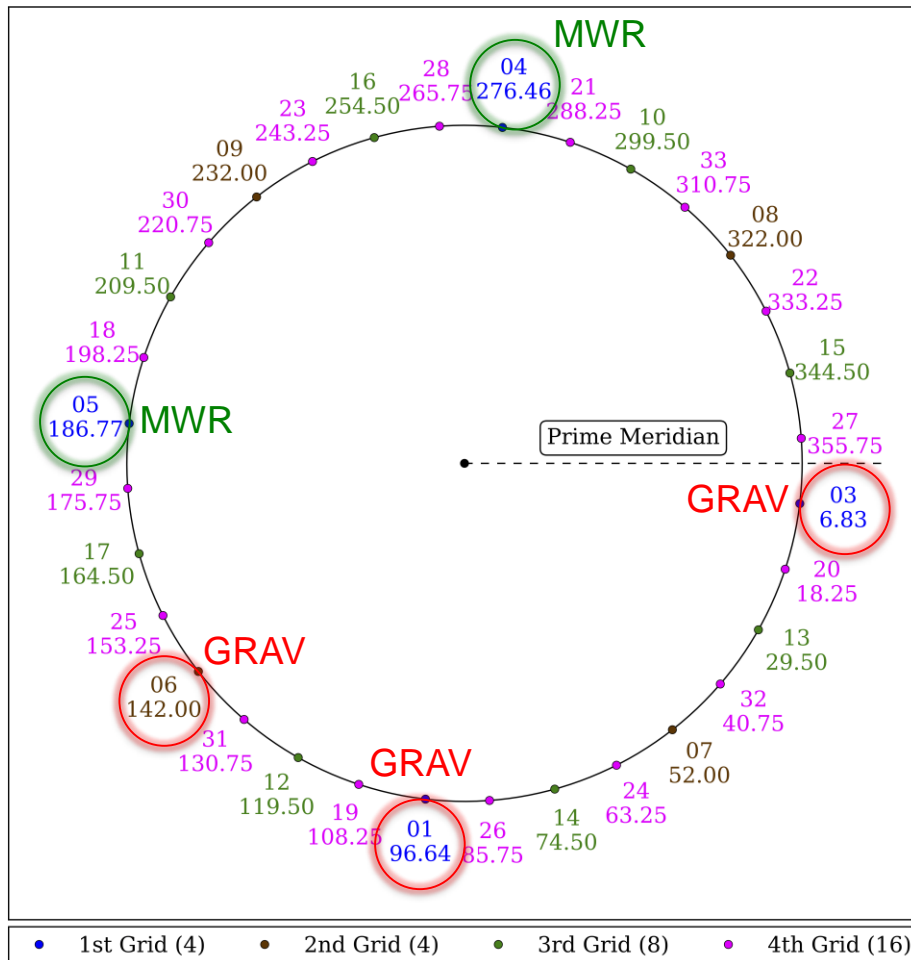Mission design
post-PRM cancellation
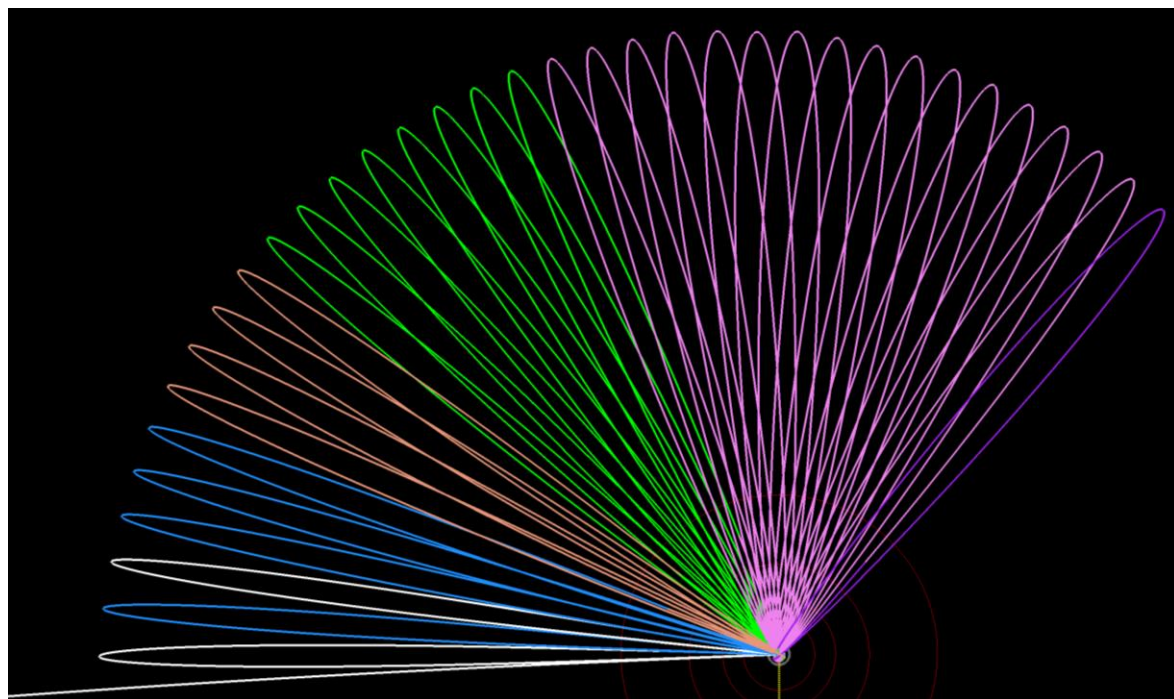
Nav Events During 53-day orbit

OTM: deterministic Orbit Trim Maneuver
APO: determinstic OTM that occurs near APOjove
STM: Statistical [Orbit] Trim Maneuver

STM(n): PJ - 2 weeks
Target: PJ(n+1)

OTM(n) DCO: PJ(n) - 1 week

S/C orbit direction

STM(n) DCO: STM(n) - 1 week

PJ(n), PJ(n+1)

Jupiter

arc epoch

AJ(n), AJ(n+1)

Ecliptic plane

APO(n): near AJ(n)
Target: PJ(n+1)

arc epoch

APO(n) DCO: APO(n) - 1 week

OTM(n): PJ(n) + 7.5 hours
Target: APO(n) or PJ(n+1)

Figure not to scale

Equator-Crossing Longitude Grid
and Two Types of Attitudes at Perijove

- **Filter setup varies, but the baseline case estimates:**
  - **State: position & velocity**
  - **Solar Radiation Pressure**
  - **Small forces**
  - **Transponder bias (constant range offset)**
  - **Maneuvers**
- **Side cases include estimating Jupiter barycenter ephemeris, DE436**
  - **transponder bias not estimated**
- **Baseline Ops OD usually ignores the PJ data**
  - **fitting PJ data during reconstruction**
  - **stochastic accelerations occasionally used for reconstruction purpose**
- **Doppler data usually compressed to 300-s**
  - **may chose to use uncompressed 5-s data when reconstructing PJ**
- **Trajectory Prediction Requirement**
  - **equator-crossing longitude target within 1-deg, 3σ (1σ = 0.333 deg)**
- **Trajectory Reconstruction Requirement**
  - **within 10-km during PJ+/-3hours**

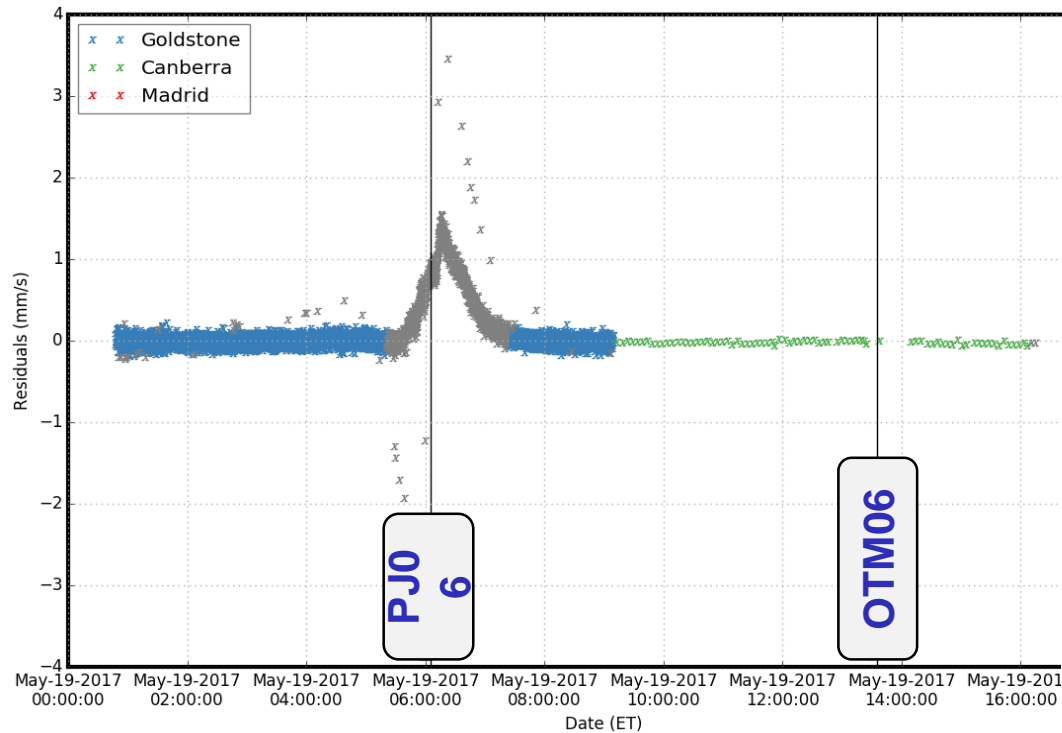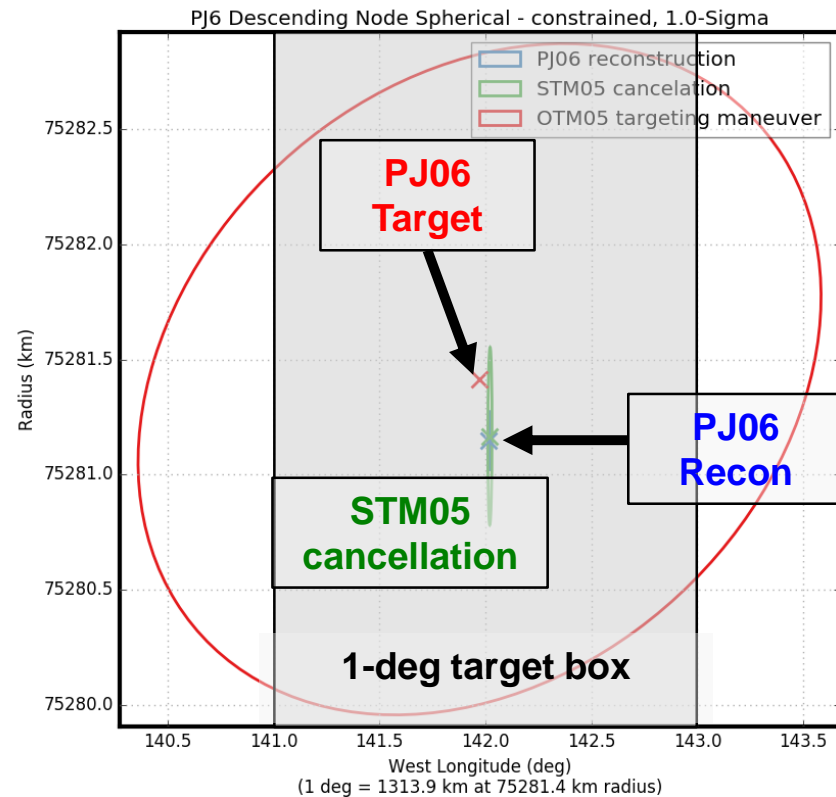# Tracking Data and Fit for Typical Arc
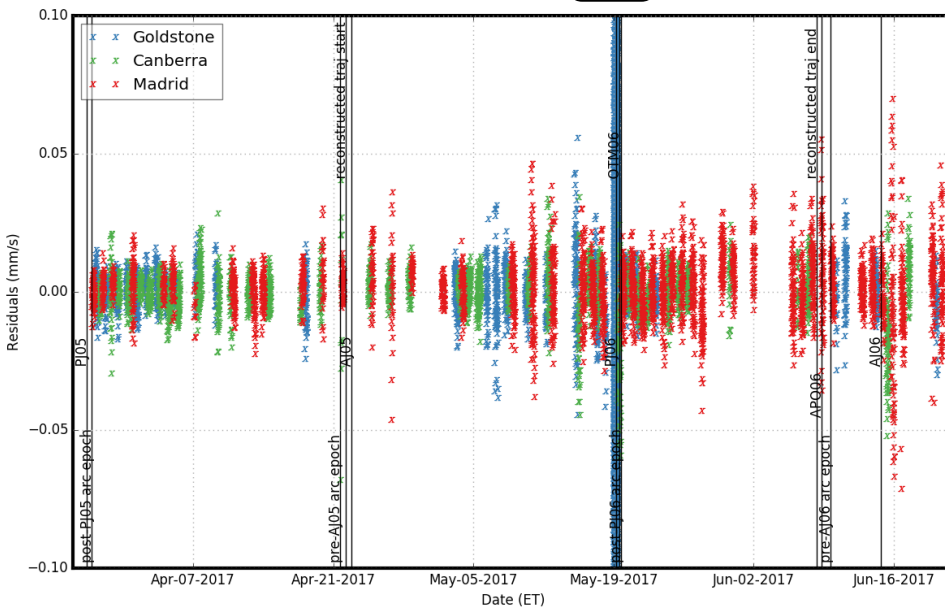
2-way Doppler
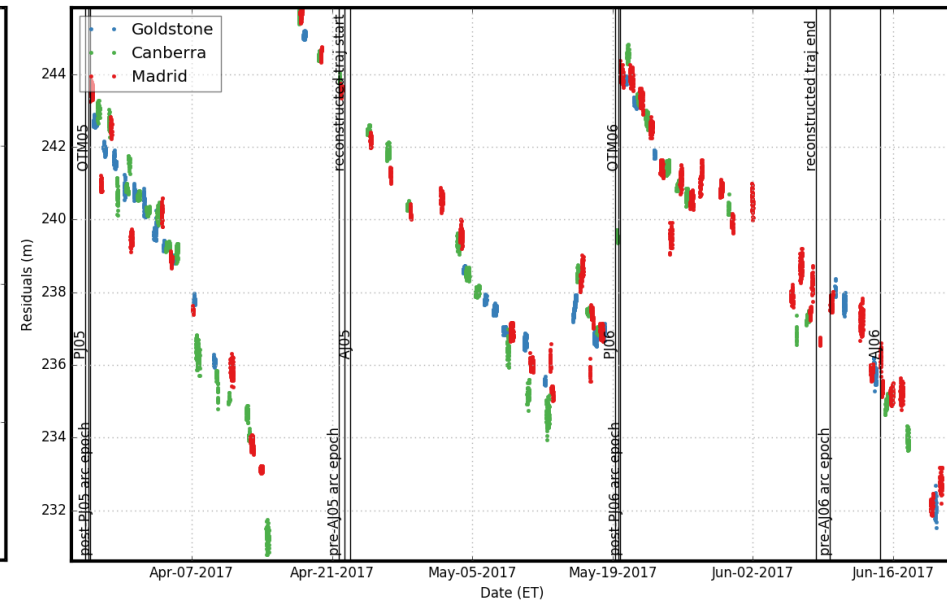
Range

PJ06 Final Results

Doppler residual points in grey
are deleted points (Io plasma torus)
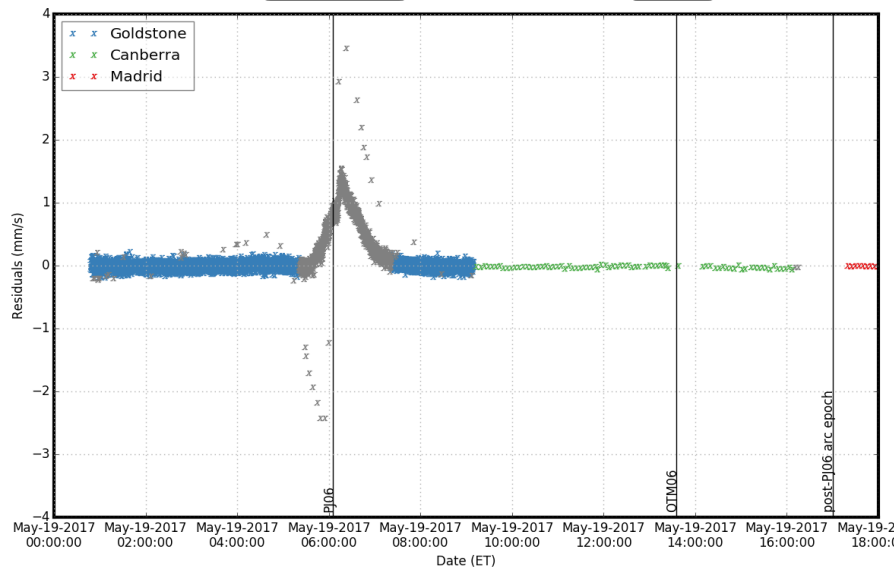and not a part of the fit

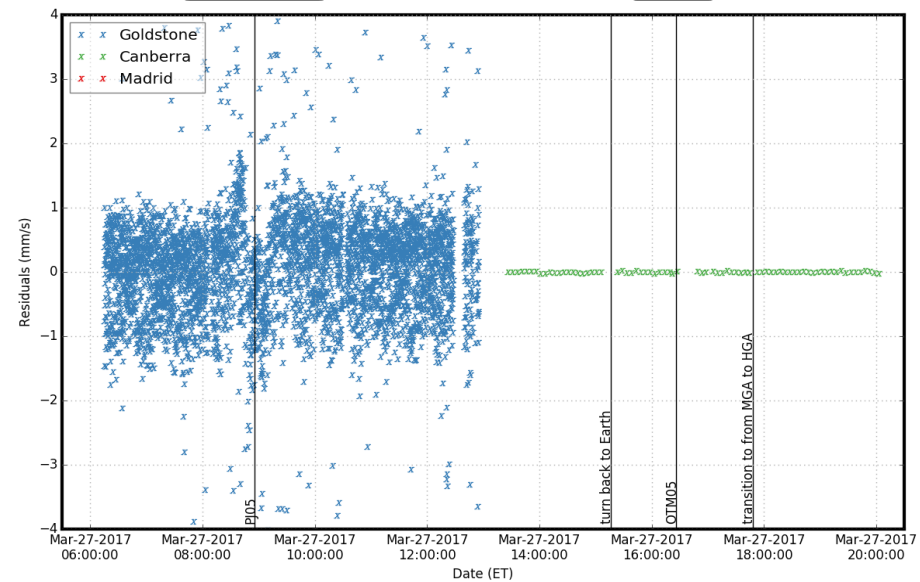# Comparison of PJ05 & PJ06 Final Results

PJ06 on HGA

OTM06

PJ05 on MGA

OTM05

Doppler residual points in grey
are deleted points (Io plasma torus)
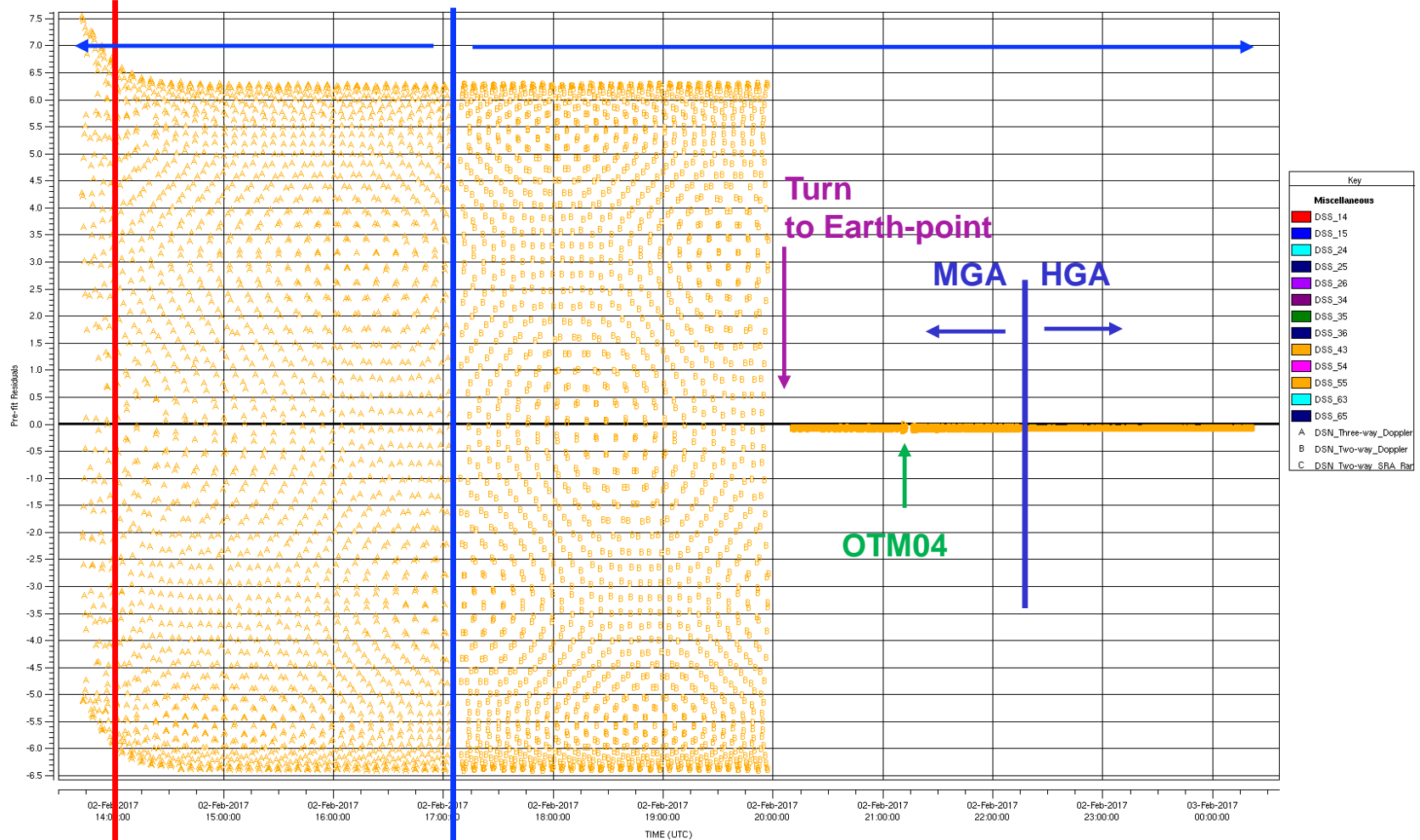and not a part of the fit

Three-way: DSS 25 – DSS 43   **Two-way: DSS 43**
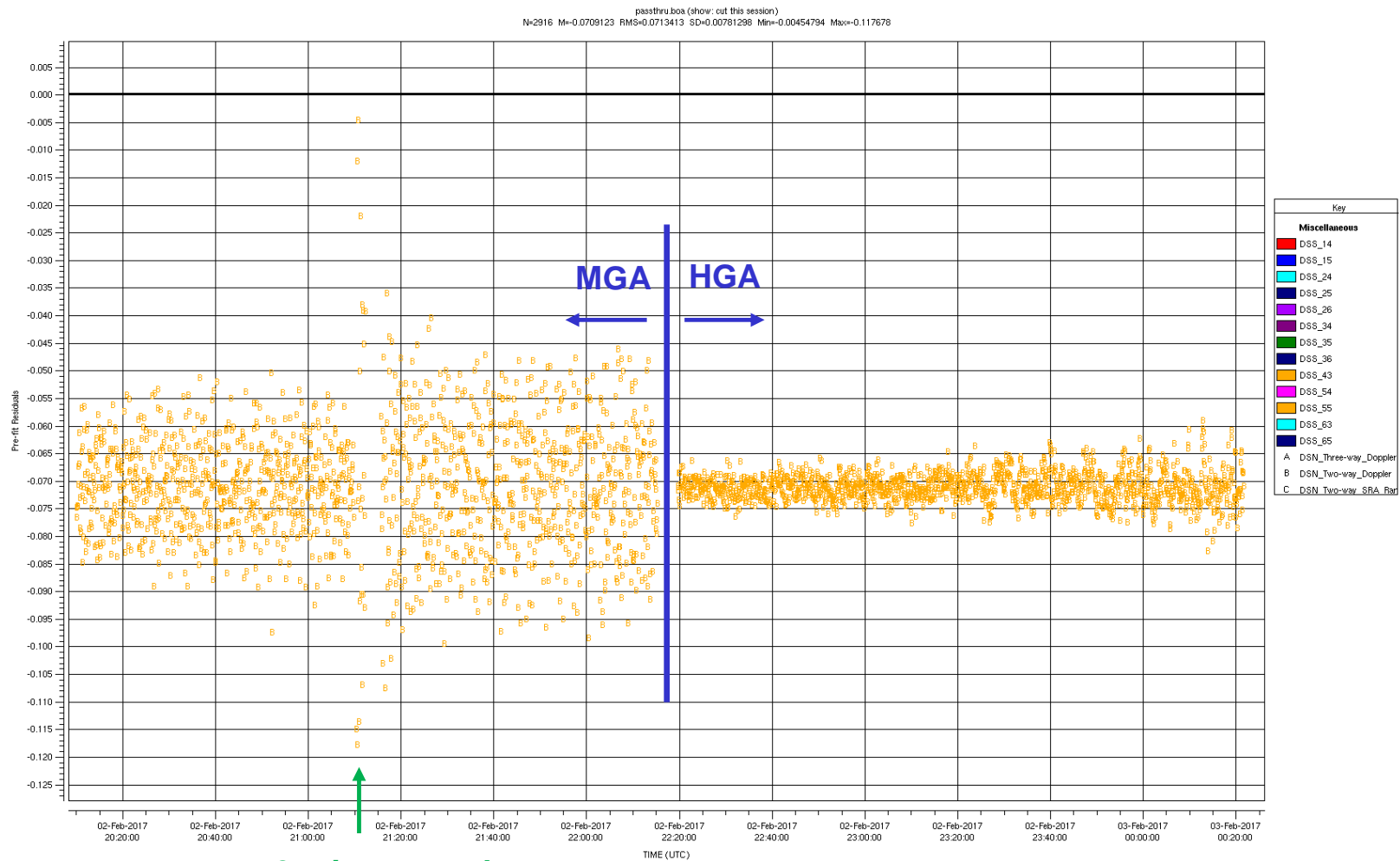
Turn to Earth-point

MGA   HGA

OTM04

PJ04

Passthru of Raw PJ4 Data
zoomed in on Earth-pointed data around OTM04

# Spin Rate Change During PJ04
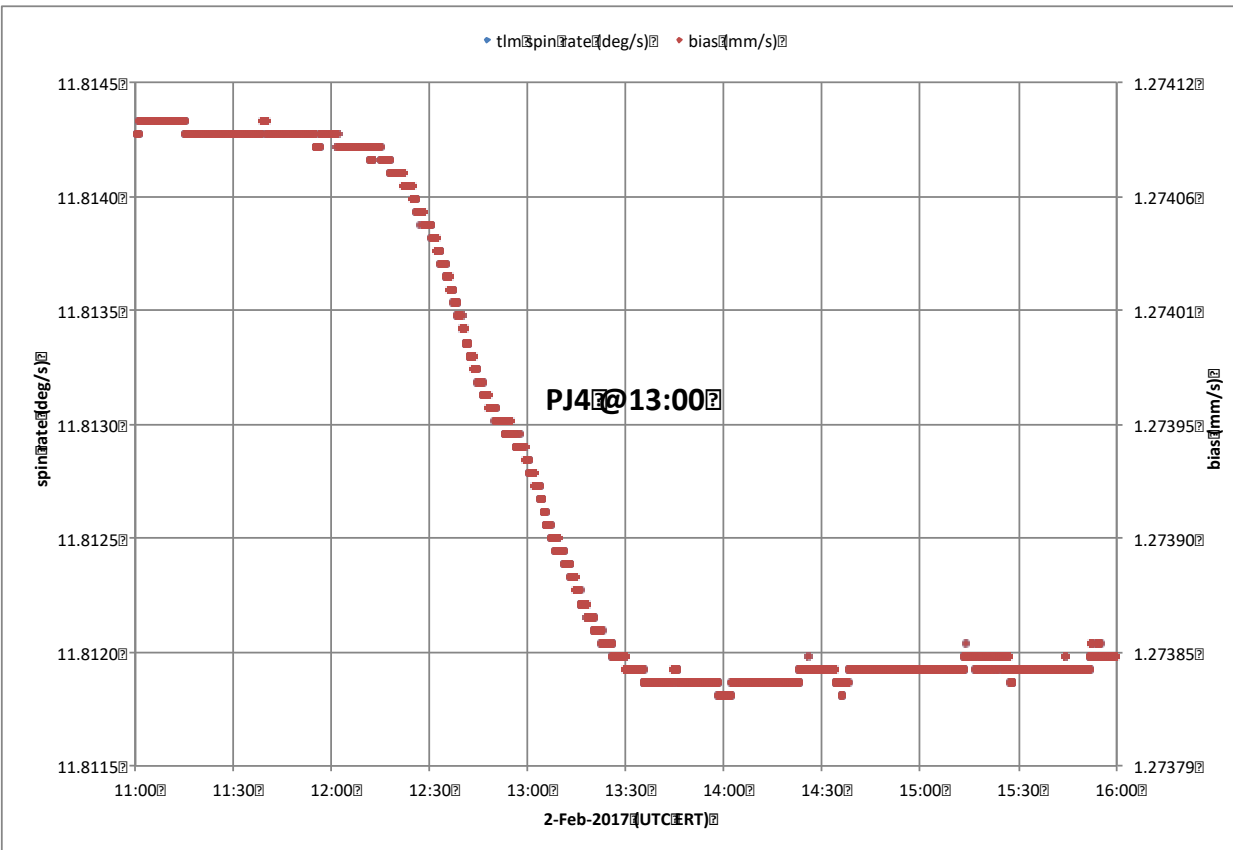
- **Spin rate change due to magnetic field torques**
- **Normally ignore when using HGA during PJ**
  - **spin-induced bias on Doppler <0.0005 mm/s**
- **Can not ignore when using MGA during PJ**
  - **despin tool assumes near constant spin rate**
  - **spin rate change too great for tool to determine valid spin state for entire PJ**
  - **broke up PJ pass into shorter segments**
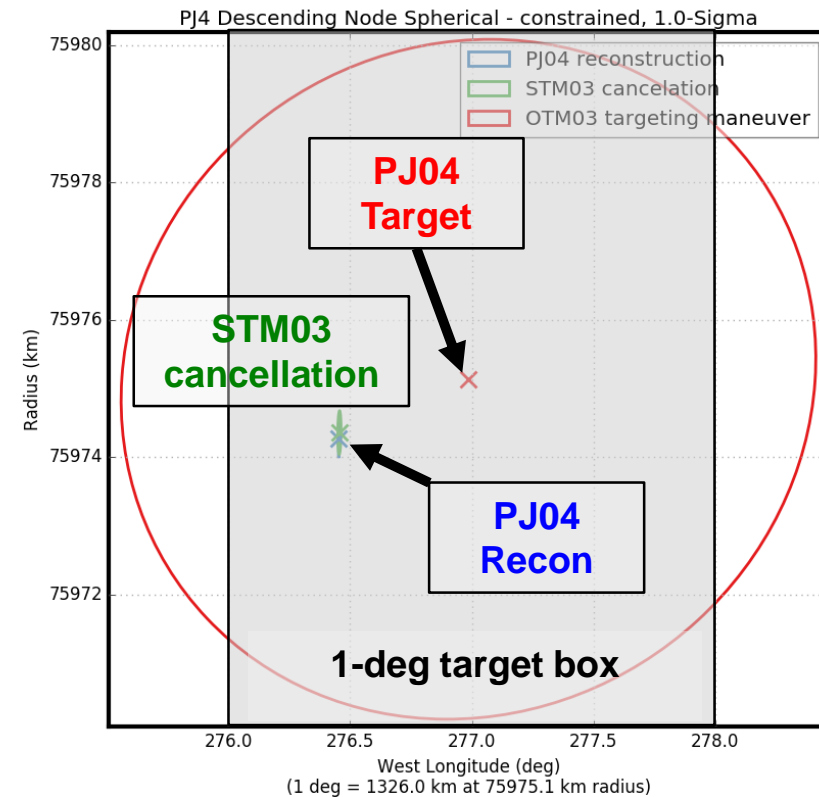- **Alternate method developed to use high-rate spacecraft telemetry for future PJs using MGA**

PJ04 Final Results
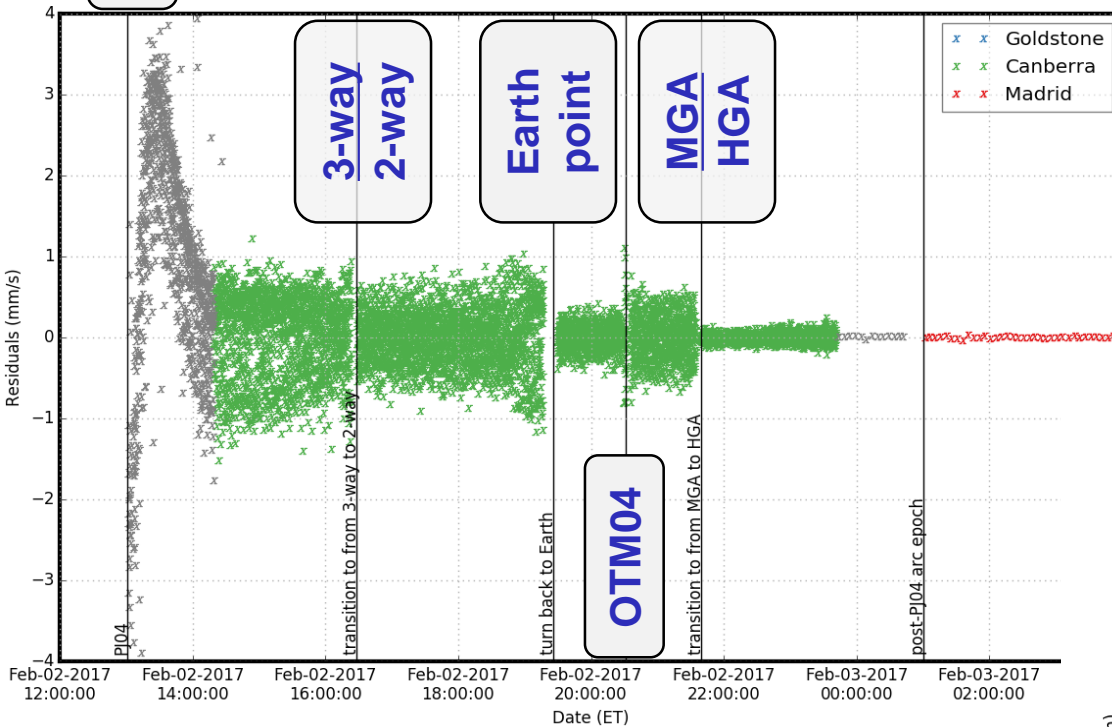
Doppler residual points in grey
are deleted points (Io plasma torus)
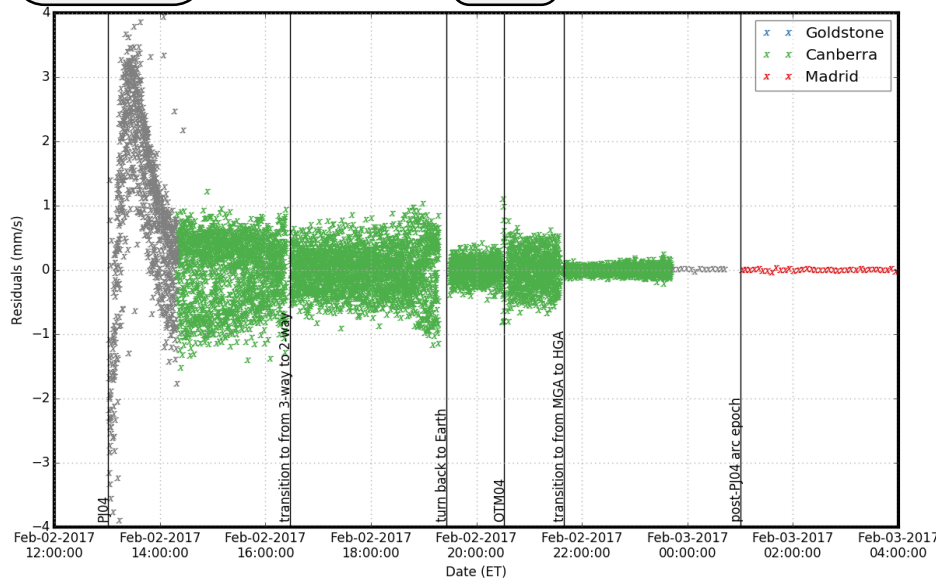and not a part of the fit
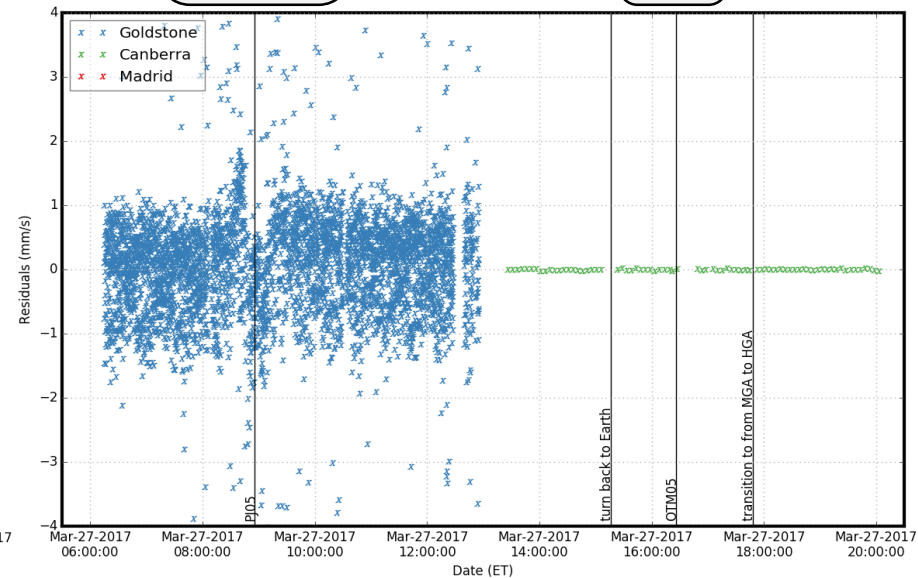
Comparison of PJ04 & PJ05 Final Results

PJ04 old way

OTM04

PJ05 new way

OTM05

Doppler residual points in grey
are deleted points (Io plasma torus)
and not a part of the fit

Summary

- **Juno successfully completed its first year in orbit**
- **Cancellation of PRM led to changes in OD process**
  - additional product deliveries and new data arc strategy
- **All reconstructed trajectories were were within 0.5° of equator-crossing longitude target**
  - all statistical maneuvers were cancelled
- **In regular communication with Solar System Dynamics group and Radio Science team**
  - collaborative relationship allowed improvement in reconstructions with better Jupiter barycenter ephemeris, gravity field, and pole orientation
- **Developed alternate method to remove spin signature from Doppler data during PJs using MGA**

Cloud tops at 7,800 mi (12,500 km)

South Pole and White Ovals

Great **Red** **Spot**